

Jan. 9, 1968

D. J. KONEVAL ET AL

3,363,119

PIEZOELECTRIC RESONATOR AND METHOD OF MAKING SAME

Filed April 19, 1965

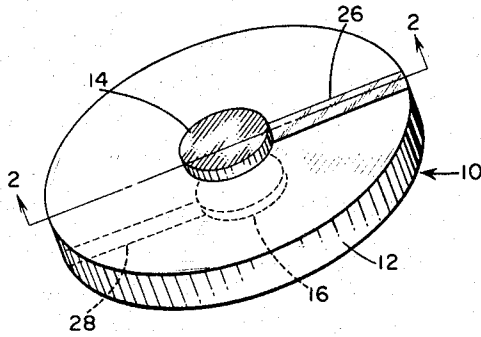


FIG. 1

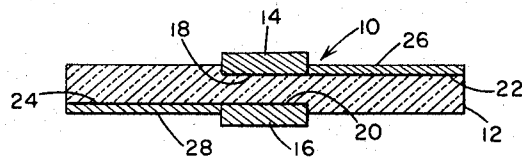


FIG. 2

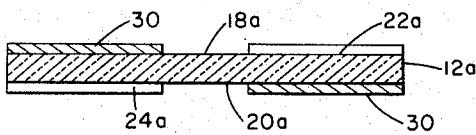


FIG. 3

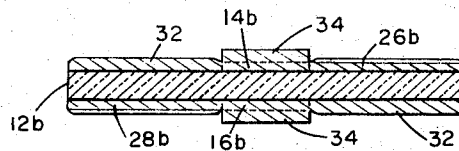


FIG. 4

INVENTORS
DONALD J. KONEVAL
DANIEL R. CURRAN

BY

James A. Smith

ATTORNEY

1

3,363,119

PIEZOELECTRIC RESONATOR AND METHOD OF MAKING SAME

Donald J. Koneval, Warrensville Heights, and Daniel R. Curran, Cleveland Heights, Ohio, assignors to Clevite Corporation, a corporation of Ohio

Filed Apr. 19, 1965, Ser. No. 448,923

9 Claims. (Cl. 310-9.5)

ABSTRACT OF THE DISCLOSURE

A piezoelectric resonator comprises a wafer of piezoelectric material provided with recesses in opposite face surfaces thereof. A pair of electrodes are positioned in the recesses respectively. The depth dimensions of the recesses are sized to provide a desired overall thickness of the electroded region relative to the non-electroded region to achieve a desired mass loading of the electroded region without varying the electrode thickness. Reference is made to the claims for a legal definition of the invention.

This invention relates to piezoelectric resonators and, specifically, to improved high frequency resonators for use in electric filter circuits and the method of making the same.

The invention has utility in connection with piezoelectric resonators comprising a thin wafer of monocrystalline or ceramic material having a vibrational mode producing a particle displacement in the plane of the wafer which is anti-symmetrical about the center plane of the wafer. Such vibrational modes include the thickness shear, thickness twist and torsional modes all of which can be obtained with piezoelectric monocrystalline materials and in piezoelectric ceramic materials.

The typical wafer type of resonator of thickness (t) is provided with electrodes of predetermined area on opposite planar surfaces thereof to enable the resonator to be excited electromechanically in its principal vibratory mode. At the resonant condition maximum particle motion and wave motion occurs.

In copending application Ser. No. 281,488 filed on May 20, 1963 by William Shockley and Daniel R. Curran and assigned to the same assignee as the present invention there are disclosed resonator structures in which wave propagation beyond the electroded region is minimized to thereby reduce the "range of action" and maximize the mechanical Q . This is accomplished by structurally establishing a relationship between the resonant frequency f_a of the electroded region and the resonant frequency f_b of the surrounding non-electroded region of the wafer whereby the frequency f_b acts as a cut-off frequency for propagation of the vibratory mode from the electroded region. The relationship is preferably such that f_a/f_b is in the range of 0.8 to .999, i.e., a value less than one, as disclosed in application Ser. No. 281,488. One disclosed method of accomplishing the frequency relationship is to utilize a calculated electrode thickness t_e relative to the thickness t_w of the wafer to effect a predetermined mass loading of the electroded region whereby its resonant frequency is decreased relative to that of the surrounding wafer material.

With respect to very high frequency (VHF) resonators the electrode mass loading concept as disclosed in application Ser. No. 281,488 for reducing wave propagation becomes difficult to use with increase in frequency.

Utilizing the mass loading concept the relationship of the electrode diameter (d) of a high frequency resonator structure with other parameters may be expressed by the following equation in accordance with the theory dis-

2

closed in our copending application Ser. No. 448,922 filed concurrently herewith:

$$d \leq \frac{Mt_w}{n} \left(\frac{f_a}{f_b - f_a} \right)^{1/2} \quad (1)$$

where M is a constant, t_w is the wafer thickness, n is the order of the harmonic (1, 3, 5, etc.), f_a is the resonant frequency of the electroded region of the wafer, f_b is the calculated cut-off resonant frequency of the surrounding non-electroded region.

The effective mechanical Q of a high frequency resonator may be expressed by the following equation:

$$Q = \frac{1}{WC_1R} \quad (2)$$

where C_1 is the motional capacitance of the resonator, W is equal to $2\pi f$, and R is the total resistance (motional resistance plus electrical resistance).

In the case of a high frequency resonator there is a substantial limitation on the maximum diameter at a given frequency which can be obtained since the electrode thickness must be decreased with increase in electrode area to achieve the desired relationship between f_a and f_b . As the electrode thickness decreases the resistance of the electrodes and leads will increase causing a reduction in mechanical Q as will be apparent from Equation 2.

It is an object of the present invention to provide a high frequency resonator possessing low resistance, high material capacitance and high mechanical Q .

Another object of the invention is to achieve a smaller degree of mass loading in a high frequency resonator while mounting a low electrical resistance.

Another object of the invention is to provide an improved method of fabricating a high frequency resonator structure.

The invention in general contemplates a resonator structure comprising a thin wafer of piezoelectric material having electrodes on opposite surfaces thereof which coat with the intervening piezoelectric material to form a piezoelectric resonator. The wafer of piezoelectric material is provided with a recess or cavity in at least one major surface thereof in which an electrode is formed or mounted. The structure of the resonator is such that the region of piezoelectric material between the two electrodes is less in thickness than the surrounding region. With this arrangement thicker electrodes can be utilized than would ordinarily be possible in a high frequency resonator having a predetermined electrode diameter since a portion of the electrode thickness forms a portion of the wafer thickness. As a result the optimum relationship between the resonant frequencies of the electroded and non-electroded regions and a low electrode resistance can be obtained for an electrode diameter corresponding to a particular frequency.

Other objects and advantages will become apparent from the following description taken in connection with the accompanying drawing wherein:

FIGURE 1 is a perspective view of a piezoelectric resonator embodying the invention;

FIGURE 2 is a section taken along line 2-2 of FIGURE 1;

FIGURES 3 and 4 are sectional views illustrating a structural modification of the resonator shown in FIGURE 1.

Referring to FIGURE 1 of the drawing there is shown a piezoelectric resonator identified generally by the reference numeral 10. In general the resonator 10 comprises a thin wafer (in this case circular) of piezoelectric material 12 having a pair of oppositely disposed electrodes 14 and 16 which coat with the intervening piezoelectric material

to define a resonator. Preferably resonator 10 is of the wafer type shown in FIGURE 1 formed from monocrystalline or ceramic material having a vibrational mode producing a particle displacement in the plane of the wafer which is antisymmetrical about the center plane of the wafer, e.g., thickness shear, thickness twist and torsional modes.

Known monocrystalline piezoelectric materials include quartz, Rochelle Salt, DKT (di-potassium tartrate), lithium sulfate or the like. As is well known to those skilled in the crystallographic arts, the basic vibrational mode of a crystal wafer is determined by the orientation of the wafer with respect to crystallographic axis of the crystal from which it is cut. It is known for example that a "0° Z-cut" of DKT or an "AT-cut" of quartz may be used for a thickness shear mode of vibration.

Of the various monocrystalline piezoelectrics available quartz, primarily because of its stability and high mechanical quality factor Q_m is a preferred material for narrow band filter applications. An "AT-cut" quartz wafer responds in the thickness shear mode to a potential gradient between its major surfaces and is particularly suitable.

For wider band filters the wafers are preferably fabricated of a suitable polarizable ferroelectric ceramic material such as barium titanate, lead zirconate-lead titanate, or various chemical modifications thereof. Suitable ceramic material for the purposes of the invention are ceramic compositions of the type disclosed and claimed in U.S. Patent No. 3,006,857 and the copending application of Frank Kulcsar and William R. Cook, Jr., Ser. No. 164,076, filed Jan. 3, 1962, and assigned to the same assignee as the present invention. Such ferroelectric ceramic compositions may be polarized by methods known to those skilled in the art. For example, a thickness shear mode of vibration may be accomplished through polarization in a direction parallel to the major surfaces of a wafer, in the manner described in U.S. Patent 2,646,610 to A. L. W. Williams.

While, as discussed, the inventive concept is equally applicable to monocrystalline or ceramic piezoelectric wafers having a vibrational mode wherein the partial motion is antisymmetrical with respect to the center plane, the disclosure will be in regard to resonators comprising an "AT-cut" quartz crystal.

In accordance with the teaching of copending application Serial No. 448,922, the resonator 10 defines an electroded region which has a resonant frequency f_a less than the resonant frequency f_b of the surrounding region. Preferably the frequencies f_a and f_b are related whereby f_a/f_b is in the range of 0.8 to .99999.

To achieve a desired electrode diameter and thickness and a desired relationship between f_a and f_b , the wafer 12 is provided with oppositely disposed recesses or cavities 18 and 20 of dimensions complimentary to the planar dimensions of the electrodes 14 and 16. The electrodes 14 and 16 are formed or received within recesses 18 and 20 and have a predetermined thickness which may exceed, equal or be less than the depth of recesses 18 and 20 depending on the density of the electrode material. In FIGURE 2 the electrodes 14 and 16 are shown as having a thickness greater than the depth of the recesses 18 and 20.

The wafer 12 is additionally provided with elongated recesses 22 and 24 on the opposite face surface thereof which extend from the wafer edge to the recesses 18 and 20 respectively. A pair of electrically conductive leads 26 and 28 are formed or received within recesses 22 and 24 respectively to facilitate attachment of electrodes 14 and 16 to electrical circuits.

The electrodes 14 and 16 and leads 26 and 28 may be separately fabricated as parts and then cemented in their respective recesses or may be formed by vapor depositing material such as aluminum, gold or silver directly into the recesses utilizing suitable masking as is necessary. Preferably, the leads 26, 28 and electrodes 14, 16 comprise vapor deposited aluminum material.

The electrode recesses 18, 20 and the lead recesses 26, 28 may be formed in the wafer surface prior to the vapor deposition process by known masking and etching techniques. Preferably, however, the wafer configuration shown in FIGURE 2 is achieved by fabricating a relatively thin wafer 12a as shown in FIGURE 3, masking the electrode and lead areas, and then vapor depositing a layer 30 of high Q insulating material such as silicon monoxide on the vapor-masked portions, the deposited layer thickness being equal to the desired depth of recesses 18a and 20a. The electrodes and leads may be subsequently vapor deposited on the wafer structure thus formed in the same manner as described in connection with FIGURE 2.

Still another technique of fabricating wafer 12 to the desired configuration is illustrated by FIGURE 4. In this embodiment a thin wafer 12b of uniform thickness is provided with a vapor deposited layer 32 of aluminum as shown in FIGURE 4 to produce a total effective thickness equal to the desired wafer thickness. The electrode and lead areas are then coated with a photoresist material whereupon the structure is submersed in an electrolyte and anodized. The aluminum layer where not protected by the resist will anodize, increase in thickness and become a dense insulating material giving the wafer the desired total effective thickness, the protected regions defining the electrode and lead regions. To achieve the desired mass loading of the electroded region additional material 34 such as aluminum, gold, silver, etc., may be vapor deposited on the non-anodized electrode regions thus formed as indicated in FIGURE 4.

In accordance with the theory disclosed in copending application Ser. No. 281,488 the resonant frequency f_a of the electroded region may be determined by the following equation:

$$f_a = \frac{N}{t_a} \left[1 + 2 \frac{\rho_e}{\rho_q} \frac{t_e}{t_a} \right]^{-1} \quad (3)$$

where ρ_e is the density of the electrode material and ρ_q is the density of the wafer material (in this case quartz), t_e is the electrode thickness, t_a is the wafer thickness in the electroded region and N is the frequency constant.

The resonant frequency f_b of the non-electroded region (b) may be expressed as follows in terms of the frequency constant N and wafer thickness t_b :

$$f_b = \frac{N}{t_b} \quad (4)$$

Combining Equations 3 and 4 the resonant frequency ratio Ω_0 may be expressed as follows:

$$\Omega_0 = \frac{f_a}{f_b} = \frac{t_b}{t_a} \left[1 + 2 \frac{\rho_e}{\rho_q} \frac{t_e}{t_a} \right]^{-1} \quad (5)$$

It will be apparent that through application of Equations 3, 4 and 5 the electroded and non-electroded regions and electrodes 14 and 16 may be selectively sized to produce a desired resonant frequency difference.

In actual practice the resonator electrode diameter is initially selected in accordance with the characteristics desired, e.g., capacitance, resistance, etc. The value determined and the frequency f_a is then inserted into Equation 1 whereupon the equation is solved for f_b . The thicknesses t_a , t_b and t_e are then determined from Equations 3 and 4.

The positioning of electrodes 14 and 16 in recesses 18 and 20 permits a substantial electrode thickness with even a large diameter electrode in a high frequency resonator while at the same time achieving the desired small value of mass loading. Optimum characteristics are thus achieved. Such positioning of the electrodes also permits use of substantially smaller mass loading than heretofore practical. Values of f_a/f_b as large as 0.99999 are feasible.

While in the disclosed embodiment of the invention the electrodes 14 and 16 are both formed in recesses it will be apparent to those skilled in the art that one electrode can be alternately positioned on the wafer surface and the other electrode positioned in a recess of increased

depth to achieve the desired effective thicknesses of the electroded and the non-electroded regions of the wafer. The recessing of both electrodes is preferred, however, because of the symmetry of the resulting structure.

The following is a tabulation of the dimensions and characteristics of a 50 megacycle 5th harmonic mode resonator in accordance with the present invention and a prior art resonator having electrodes mounted on the wafer surface in the conventional manner, the electrode diameter being the same in both resonators:

	Prior Art Resonator	Resonator Embodying Invention
Total Resistance, R_T	84 ohms.....	64 ohms.
Static Capacitance, C_0	1.58 pf.....	1.58 pf.
Motional Capacitance, C_1	2.91×10^{-4} pf.....	2.91×10^{-4} pf.
Mechanical Q, Q_m	129,000.....	170,000.
f_a/f_b	0.999.....	0.999.
Electrode Thickness, t_e	770 Angstroms.....	2,310 Angstroms.
Lead Resistance, R_L	30 ohms.....	10 ohms.

In the above example the lead resistance R_L was estimated using measured resistivity at 50 megacycles of an aluminum thin film ($t=526$ Angstroms) deposited in the same manner.

From the above data it will be apparent that the present invention permits the electrode thickness to be increased substantially resulting in a substantial decrease in electrode resistance and a substantial increase in mechanical Q.

The invention has utility in connection with multi-resonator structures such as disclosed in copending application Ser. No. 216,846. The individual electrodes may be selectively recessed in the manner illustrated in FIGURE 2 to achieve the desired characteristics.

While there have been described what at present are believed to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is aimed, therefore, to cover in the appended claims all such changes and modifications as fall within the true spirit and scope of the invention.

It is desired to secure by Letters Patent of the United States:

1. A piezoelectric resonator comprising: a thin wafer of piezoelectric material defining a center plane and having a vibratory mode in which the particle displacement is anti-symmetrical relative to said plane; a pair of recesses on opposite major surfaces of said wafer respectively; and a pair of electrodes having a predetermined thickness positioned in said recesses, respectively; said electrodes and the interposed wafer material defining an electroded region having a resonant frequency f_a related to the overall thickness of the electroded region, the surrounding non-electroded region of the wafer defining a second higher resonant frequency f_b related to the thickness of the wafer, said recesses having a predetermined depth to achieve a predetermined overall thickness of the electroded region relative to the non-electroded region to achieve a predetermined ratio f_a/f_b while maintaining said predetermined thickness of said electrodes.

2. A piezoelectric resonator as claimed in claim 1 wherein said wafer is provided with elongated recesses on opposite said wafer is provided with elongated recesses on opposite surfaces thereof and said resonator includes conductive leads for said electrodes positioned in said elongated recesses.

3. A piezoelectric resonator as claimed in claim 2 wherein said electrodes and leads comprise electrically conductive material vapor deposited in said recesses.

4. A piezoelectric resonator comprising: a thin wafer of piezoelectric material having a thickness shear mode of vibration; a pair of recesses on opposite major sur-

faces of said wafer; a pair of electrodes positioned in said recesses respectively; said electrodes having a predetermined thickness and the interposed wafer material defining an electroded region having a resonant frequency f_a related to the overall thickness of the electroded region, the surrounding non-electroded region of the wafer defining a second higher resonant frequency f_b related to the thickness of said wafer; said first and second resonant frequencies being related whereby f_a/f_b is in the range of 0.8 to 0.99999; said recesses having a depth dimension sized to achieve a desired overall thickness of the electroded region to achieve a desired ratio f_a/f_b within said range without varying said predetermined electrode thickness.

5. A piezoelectric resonator as claimed in claim 4 wherein said electrodes and recesses are of circular configuration.

6. A piezoelectric resonator as claimed in claim 5 wherein said wafer material is quartz.

7. A piezoelectric resonator as claimed in claim 5 wherein said wafer material is piezoelectric ceramic material.

8. A high frequency piezoelectric resonator comprising: a thin wafer of piezoelectric material defining a center plane and having a thickness predetermined t and a vibratory mode in which the particle displacement is anti-symmetrical relative to said center plane; a pair of circular recesses in opposite face surfaces of said wafer respectively; a pair of circular electrodes positioned in said recesses respectively having a predetermined diameter d ; said electrodes and the interposed wafer material defining a first region in said wafer having a first resonant frequency f_a related to the overall thickness of said first region surrounded by a second region in said wafer having a resonant frequency f_b related to the thickness of said wafer; said first and second resonant frequency being related whereby f_a/f_b is in the range of 0.8 to 0.99999; said wafer and electrodes being dimensioned whereby d , f_a , f_b and t are related in accordance with the following equation:

$$d \leq \frac{Mt}{n} \left[\frac{f_a}{f_b - f_a} \right]^{1/2}$$

where M is a constant and n is the harmonic order of frequency f_a said recesses having a depth dimension sized to achieve a desired overall thickness of said first region and a desired value of f_a/f_b within said range.

9. A piezoelectric resonator comprising: a thin wafer of piezoelectric material having opposite major surfaces and a recess in at least one of said surfaces; and a pair of electrodes each having a predetermined thickness positioned on said surface respectively to define an electroded region in said wafer having a resonant frequency f_a related to the overall thickness of the electroded region and to define a surrounded non-electroded region having a resonant frequency f_b higher in magnitude than the frequency f_a ; one of said electrodes being positioned in said recess to decrease the overall thickness of said electroded region and to increase the frequency f_a relative to the frequency f_b to achieve a higher ratio f_a/f_b without decreasing the thickness of said electrodes.

References Cited

UNITED STATES PATENTS

3,249,176	9/1965	Paley	710—82
2,901,644	8/1959	Tibbetts	710—9.1
2,482,661	9/1949	Demmick	310—9.2
2,481,806	9/1949	Wolfskill	310—9.7
2,859,346	11/1958	Firestone	310—9.5

MILTON O. HIRSHFIELD, *Primary Examiner*.

J. D. MILLER, *Assistant Examiner*.